

## CLAIMS

What is claimed is:

1. An electroluminescent device comprising: /  
5 an inorganic phosphor configured to produce electroluminescence from the recombination of injected holes and injected electrons;  
a controllable hole injection structure in contact with the inorganic phosphor; and  
a controllable electron injection structure in contact with the inorganic phosphor  
and separated from the controllable hole injection structure by a  
10 recombination region of the inorganic phosphor.
2. The electroluminescent device of claim 1, wherein a first applied control voltage controls a rate of hole injection into the inorganic phosphor.
- 15 3. The electroluminescent device of claim 1, wherein a second applied control voltage controls a rate of electron injection into the inorganic phosphor.
4. The electroluminescent device of claim 1, wherein a third applied voltage controls an electroluminescence intensity produced by the device.  
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5. The electroluminescent device of claim 1, wherein  
a first applied control voltage controls a rate of hole injection into the inorganic phosphor;  
a second applied control voltage controls a rate of electron injection into the  
25 inorganic phosphor independently of the first applied control voltage;  
a third applied control voltage controls an electroluminescence intensity produced by the device independently of the first and second applied control voltage.

6. The electroluminescent device of claim 1, wherein the inorganic phosphor is selected from the group consisting of ZnS, SrS, BaS, CaS, ZnO, ZnSe, GaN, and GaP.

5 7. The electroluminescent device of claim 1, wherein the controllable hole injection structure comprises:

a hole injection region in contact with the inorganic phosphor and configured to receive a hole-injection bias voltage; and

10 a field effect gate structure in contact with the inorganic phosphor substantially opposite the hole injection region and configured to receive the first applied control voltage.

15 8. The electroluminescent device of claim 7, wherein the field-effect gate structure further comprises a portion extending beyond the edge of the hole-injection region and towards the recombination region.

9. The electroluminescent device of claim 7, wherein the hole injection region has a thickness less than a thickness of the inorganic phosphor.

20 10. The electroluminescent device of claim 7, wherein the hole injection region is formed from the same material as the inorganic phosphor.

11. The electroluminescent device of claim 7, wherein the hole injection region is formed from a high work function metal.

25 12. The electroluminescent device of claim 11, wherein the high work function metal is selected from the group consisting of Au, Pt, Pd, and Ni.

13. The electroluminescent device of claim 7, wherein the hole injection region is formed from a p-type doped semiconductor.

14. The electroluminescent device of claim 13, wherein the p-type  
5 doped semiconductor is selected from the group consisting of NiO, Cu<sub>2</sub>O, Co<sub>3</sub>O<sub>4</sub>, SrCu<sub>2</sub>O<sub>2</sub>, CuAlO<sub>2</sub>, CuYO<sub>2</sub>, CuScO<sub>2</sub>, CuCrO<sub>2</sub>, CuInO<sub>2</sub>, BaCu<sub>2</sub>S<sub>2</sub>, LaCuOS, and GaN.

15. The electroluminescent device of claim 7, wherein the field effect gate  
10 structure is fabricated of transparent material.

16. The electroluminescent device of claim 7, wherein the field effect gate structure comprises:  
an injection control gate; and  
15 an injection control gate insulator layer interposed between the injection control gate and the inorganic phosphor.

17. The electroluminescent device of claim 16, wherein the injection control gate is formed from a transparent, conductive material.  
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18. The electroluminescent device of claim 17, wherein the transparent, conductive material is selected from the group consisting of In<sub>2</sub>O<sub>3</sub>, SnO<sub>2</sub>, and ZnO.

19. The electroluminescent device of claim 7, further comprising  
25 a hole injector contact in contact with the hole injection region.

20. The electroluminescent device of claim 19, wherein the hole injector contact is also in contact with the inorganic phosphor.

21. The electroluminescent device of claim 1, wherein the controllable electron injection structure comprises:  
an electron-injection region in contact with the inorganic phosphor and configured  
5 to receive an electron-injection bias voltage; and  
a field effect gate structure in contact with the inorganic phosphor substantially opposite the electron-injection region and configured to receive the second applied control voltage.

10 22. The electroluminescent device of claim 21, wherein the field-effect structure further comprises a portion extending beyond the edge of the hole-injection region and towards the recombination region

15 23. The electroluminescent device of claim 21, wherein the electron injection region has a thickness less than a thickness of the inorganic phosphor.

24. The electroluminescent device of claim 21, wherein the electron injection region is formed from the same material as the inorganic phosphor.

20 25. The electroluminescent device of claim 21, wherein the electron injection region is formed from a low work function metal.

25 26. The electroluminescent device of claim 25, wherein the low work function metal is selected from the group consisting of Ca, Li, K, Na, Mg, Sc, In, Al, Ti, Ta, and Ag.

27. The electroluminescent device of claim 21, wherein the electron injection region is formed from an n-type doped semiconductor.

28. The electroluminescent device of claim 27, wherein the n-type doped semiconductor is selected from the group consisting of ZnO, SnO<sub>2</sub>, In<sub>2</sub>O<sub>3</sub>, and GaN.

5            29. The electroluminescent device of claim 21, wherein the field effect gate structure is fabricated of transparent material.

30. The electroluminescent device of claim 21, wherein the field effect gate structure comprises:

10            an injection control gate; and  
              an injection control gate insulator layer interposed between the injection control gate and the inorganic phosphor.

31. The electroluminescent device of claim 30, wherein the injection  
15            control gate is formed from a transparent, conductive material.

32. The electroluminescent device of claim 31, wherein the transparent, conductive material is selected from the group consisting of In<sub>2</sub>O<sub>3</sub>, SnO<sub>2</sub>, and ZnO.

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33. The electroluminescent device of claim 21, further comprising an electron injector contact in contact with the electron injection region.

34. The electroluminescent device of claim 33, wherein the electron  
25            injector contact is also in contact with the inorganic phosphor.

35. The electroluminescent device of claim 1, wherein the controllable hole injection structure comprises:

a hole injection region in contact with the inorganic phosphor and configured to receive a hole-injection bias voltage,

5 a hole injection control gate insulator layer in contact with the inorganic phosphor substantially opposite the hole injection region, and

a hole injection control gate in contact with the hole injection control gate insulator; and wherein the controllable electron injection structure comprises:

10 an electron injection region in contact with the inorganic phosphor and configured to receive an electron-injection bias voltage,

an electron injection control gate insulator layer in contact with the inorganic phosphor substantially opposite the electron injection region, and

15 an electron injection control gate in contact with the electron injection control gate insulator.

36. The electroluminescent device of claim 35, wherein the hole injection region is located on the opposite side of the inorganic phosphor from the electron injection region.

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37. The electroluminescent device of claim 36, wherein a portion of the hole injection control gate is opposite a portion of the electron injection control gate.

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38. The electroluminescent device of claim 35, wherein the hole injection region is located on the same side of the inorganic phosphor as the electron injection region.

39. The electroluminescent device of claim 35, wherein the hole injection control gate insulator and the electron injection control gate insulator are formed of a single layer.

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40. A display comprising a plurality of electroluminescent devices,  
wherein the electroluminescent devices comprise: ✓

an inorganic phosphor configured to produce electroluminescence from the

5 recombination of injected holes and injected electrons;

a controllable hole injection structure in contact with the inorganic phosphor; and

a controllable electron injection structure in contact with the inorganic phosphor

and separated from the controllable hole injection structure by a

recombination region of the inorganic phosphor.

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41. The display of claim 40, further comprising a capacitor configured to  
hold a hole injection control voltage applied to the controllable hole injection  
structure.

15 42. The display of claim 40, further comprising a capacitor configured to  
hold an electron control voltage applied to the controllable electron injection  
structure.

43. An electroluminescent device comprising:

20 an inorganic phosphor means for producing electroluminescence from the  
recombination of injected holes and injected electrons; ✓

a controllable hole-injection means for controllably injecting holes into the  
inorganic phosphor means while substantially containing hole injection  
electric fields within the controllable hole-injection means; and

25 a controllable electron-injection means for controllably injecting electrons into the  
inorganic phosphor means while substantially containing electron injection  
electric fields within the controllable electron-injection means.

44. The electroluminescent device of claim 43, further comprising a voltage means for applying a voltage to the controllable hole injection means whereby injection of holes into the inorganic phosphor is enabled.

5           45. The electroluminescent device of claim 44, further comprising a control means for varying the voltage means whereby a rate of injection of holes into the inorganic phosphor means is varied.

10           46. The electroluminescent device of claim 43, further comprising a voltage means for applying a voltage to the controllable electron injection means whereby injection of electrons into the inorganic phosphor means is enabled.

15           47. The electroluminescent device of claim 46, further comprising a control means for varying the voltage means whereby a rate of injection of electrons is varied.

20           48. The electroluminescent device of claim 43, further comprising an electroluminescent voltage means for causing drift of holes and electrons within the inorganic phosphor means.

25           49. The electroluminescent device of claim 48, further comprising an electroluminescent control means for varying the electroluminescent voltage means whereby an electroluminescent intensity is varied.

30           50. The electroluminescent device of claim 43, wherein the controllable hole injecting means further comprises:  
a hole injecting means for providing hole injection into the inorganic phosphor means whereby a hole injection barrier is created; and  
a hole field effect means for overcoming the hole injection barrier.



51. The electroluminescent device of claim 43, wherein the controllable electron injecting means further comprises:  
an electron injecting means for providing electron injection into the inorganic phosphor means whereby an electron injection barrier is created; and  
5 an electron field effect means for overcoming the electron injection barrier.

52. A method of making an electroluminescent device, the method comprising:  
forming a first part of a hole injection structure;  
10 forming a first part of an electron injection structure separated from the first part of the hole injection structure;  
depositing an inorganic phosphor layer spanning an area between and at least overlapping the first part of the hole injection structure and the first part of the electron injection structure;  
15 forming a second part of the hole injection structure in contact with the inorganic phosphor layer substantially opposite the first part of the hole injection structure; and  
forming a second part of the electron injection structure in contact with the inorganic phosphor layer substantially opposite the first part of the  
20 electron injection structure and separated from the hole injection structure.

53. The method of claim 52, wherein the forming a first part of a hole injection structure further comprises forming the first part of the hole injection  
25 structure on a substrate and wherein the forming a first part of an electron injection structure further comprises forming the first part of the electron injection structure on the substrate.

54. The method of claim 52, wherein the forming a first part of the hole injection structure further comprises:

forming a hole gate electrode layer;

forming an insulator layer at least covering the hole gate electrode; and

5 wherein the forming the second part of the hole injection structure further comprises forming a hole injection layer in contact with the inorganic phosphor substantially opposite the first part of the hole injection structure.

10 55. The method of claim 52, wherein the forming a first part of the hole injection structure further comprises forming a hole injection layer.

56. The method of claim 52, wherein the forming a second part of the hole injection structure further comprises:

15 forming an insulator layer on the inorganic phosphor substantially opposite the first part of the hole injection structure; and

forming a hole gate electrode layer on top of the insulator layer substantially opposite the first part of the hole injection structure.

20 57. The method of claim 52, wherein the forming a first part of the electron injection structure further comprises:

forming an electron gate electrode layer; and

forming an insulator layer at least covering the electron gate electrode.

25 58. The method of claim 52, wherein the forming a second part of the electron injection structure further comprises forming an electron injection layer in contact with the inorganic phosphor substantially opposite the first part of the electron injection structure.

59. The method of claim 52, wherein the forming a first part of the electron injection structure further comprises forming an electron injection layer and wherein the forming a second part of the electron injection structure further comprises:

- 5 forming an insulator layer on the inorganic phosphor layer substantially opposite the first part of the electron injection structure; and forming an electron gate electrode layer on top of the insulator layer substantially opposite the first part of the electron injection structure.

- 10 60. An electroluminescent device produced in accordance with the method of claim 52.

61. A method of producing electroluminescence in an inorganic phosphor, comprising:

- 15 injecting holes into the inorganic phosphor at a first location; and injecting electrons into the inorganic phosphor at a second location separated from the first location so that a recombination region with low applied electric fields is created in a recombination region of the inorganic phosphor.

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62. The method of claim 61, further comprising:  
controlling a rate of injection of the holes; and  
controlling a rate of injection of the electrons.

- 25 63. A method of producing electroluminescence in an inorganic phosphor, comprising:

injecting holes into the inorganic phosphor; ✓  
injecting electrons into the inorganic phosphor;  
controlling a rate of injection of the holes; and  
30 controlling a rate of injection of the electrons.